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THE ROLE OF ENGINEERING GEOLOGY IN THE ASSESSMENT OF WASTE DISPOSAL FACILITY.

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ABSTRACT

Wastes are unwanted materials which are unfit for use and they could be generated from industrial, extractive, municipal or agricultural activities. Wastes can be disposed off in various ways such as landfilling, ocean dumping, open dumping or can be reduced in volume by recycling, incinerating and compacting. Ocean dumping puts wastes out of the sight of the people but contributes to the pollution of the oceans to which the world turns increasingly for food. Open dumping is inexpensive, but poses a serious health hazard, damage due to air pollution, groundwater and runoff pollution. Incineration as means of waste disposal provides a partial solution, but also poses a serious hazard of air pollution. Recycling and re-use is a waste reduction strategy because some wastes cannot be recycled. The main objective of this paper is to highlight the requirements of involving the appropriate professionals in the construction and management of wastes disposal facilities. Due to the health hazards involved in the above mentioned methods of disposal, landfills which are carefully engineered depressions in the ground into which wastes are put until rendered innocuous through physical, chemical and biological degradation, remains the most useful tool in municipal solid waste management. Prior to the design and construction of a landfill site, geological, geophysical and geotechnical characteristics of the site must be investigated to ensure the best location, stability of the facility and to minimize its effects both in the short and long terms. Once a suitable site has been located, the engineering construction of the facility can begin. A clay liner is usually placed at the base of the excavated surface. When the final elevations are reached, a low permeability capping layer is placed. Boreholes and sampling points should be installed down gradient to monitor the impact of leachate on the underlying groundwater. The most suitable after-uses of landfill sites include parks, pasture land, parking lots, recreational activities and other facilities not requiring much excavation.

KEY WORDS: Leachate, Landfill, Waste, Engineering, Geology**.**

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INTRODUCTION

Inadequate final waste disposal, i.e. open dumping of solid waste thrives because of the mistaken belief that it is the cheapest disposal method. Deposition along roads and river banks or in abandoned quarries and hoping it will go away is both naïve and dangerous. It is inevitable that the chemical and biological contaminants in wastes will find their way back to humans to affect health, quality of life and working activities. Soluble and suspended contaminants in water leaking from the sites known as leachates will enter surface water courses and groundwater. Contamination may then directly affect the drinking water supplies and/or the aquatic food chain. Many synthetic chemicals and hydrocarbons, if they should enter the water supply, may pose long range problems to humans and the environment. Hazardous substances may induce alterations in the genetic/hereditary makeup (mutagenicity), abnormality in various forms (teratogenicity), various cancers (carcinogenicity) and other effects (Hoare, 1982). Therefore, groundwater pollution/contamination is better prevented than treated (Offodile, 2002).

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Over the years, a lot has been proposed concerning the need for proper disposal of waste, especially through the construction of appropriate waste disposal sites (Ogunsanwo and Mands, 1998). In certain parts of the world these proposals have been adopted, and are currently being put into use. The aim of designing a landfill is to make available a facility that will provide a reasonable degree of safety to humans and the environment during its operational as well as its post closure life. Therefore in designing a waste disposal site, the topography, hydrology, hydrogeology and geology of the area are considered essential pieces of information. Consequently, site selection and investigation are critical steps in the search for a landfill site as they provide key evidence on which technical, environmental and economic feasibility of the project must be based. In both site selection and investigation, engineering geology plays key roles. Engineering geology employs methods such as aerial photographs and satellite imageries which serve as useful guides to identifying geological and hydrogeological features and so reveal areas on which landfill sites might be located (Rushbrook and Pugh, 1995).

OBJECTIVES

The main objectives of this paper are:

- To sensitize the public on the need to protect the environment from the harmful effects of wastes if disposed indiscriminately.
- To make available the basic requirements of involving the appropriate professionals in the construction of safe facilities for the purpose of waste disposal.
- To provide adequate planning and investigative information on the techniques of managing wastes in a developing country.

SIGNIFICANCE OF ENGINEERING GEOLOGY IN PLANNED WASTE DISPOSAL PROGRAMMES

Engineering geology is a branch of human knowledge that uses geological information combined with practice and experience to assist in the solution of problems in which such knowledge may be applicable. Prior to the design and construction of a waste disposal site, geomorphological, geological, subsurface and soil characteristics of the site must be investigated to ensure the best siting, stability of the facility and to minimize the effects of the sites both in short and long term. The investigations involved in the acquisition of these characteristics can be obtained using engineering geological techniques.

Once a suitable site has been located, the engineering construction of the facility can begin. The engineering geologist and hydrogeologists should advice on the engineering characteristics of the soil (e.g. Atterberg limits), site settlement, site geometry, hydrologic cycle and groundwater flow patterns, leachate management and the artificial barrier (e.g. geomembranes) systems to use. A clay liner is usually placed at the base of the excavated surface. When the final elevations are reached, a low permeability capping layer is placed. Boreholes and sampling points should be installed down gradient to monitor the impact of leachate on the underlying groundwater.

SITE SELECTION

By and large, site selection is a process of screening and comparing available sites for a particular proposed development (Olatunde, 2005). Screening may involve the blocking off of unacceptable sites. The reason for unacceptability may include excessive cost, poor conditions (e.g. poor soil), previous development, lack of access, etc. The general process of landfill site selection is a step-by-step sequence. According to Van Westen (1997), when selecting a site for waste disposal, the following criteria must be taken into consideration:

(a) The waste disposal should not be built near landslides which are active or which may become active in the future.
(b) Geological structures such as faults, fractures, cavities/sinkholes, etc. that may act as pathways for leachates, must not be present in the location.
(c) The waste disposal location should be located on a terrain with a slope less than 20^0, to prevent erosion and assure accessibility.
(d) The waste disposal location should be in areas that do not have an important economic or ecological value.
(e) The waste disposal should be constructed on clay-rich soils, with permeability lower than 0.05 metres/day.
(f) The overburden at the location should not be less than 5 m.

(g) The waste disposal must be at least 300 m from any built-up area.
(h) Water must not be allowed to seep into the location from the local drainage system.
(i) The wastes disposal site should have an area of at least 1 hectare.

Therefore, to adequately evaluate the suitability of the site for a waste disposal facility, the following data sets are required:
(j) The geomorphological (slope) map of the site.
(ii) The geological map of the site.
(iii) The proposed land use and road network maps of the site.
(iv) The overburden thickness of the site.
(v) The geotechnical (engineering geological) characteristics of materials at the site.

The first step in selecting a site for a landfill is by constraint mapping which reveals the areas in which landfills may be located (subject to further criteria). Aerial photographs are a useful aid to identify geological and hydrogeological features (Rushbrook and Pugh, 1995). The output from the constraint mapping will suggest areas of search for possible sites. The target land area required, expected volume of waste over a site's life may be used as a guide to identify areas, preferably in single ownership and in a state of non-use. Where leachates may be expected to be produced, landfills should be sited in areas where its control or accidental discharge will have little or no impact on the local environment.

The first areas to seek out will be areas having geology favorable to containing or at least inhibiting the release of leachate to the wider environment for example clays and silt deposits. Depending on the restrictions imposed by the constraint mapping, a major city should aim to draw up a list of up to five possible sites identified for their positive features, these may include:

- Easy access to a road system.
- Proximity to the urban areas.
- Ease of land acquisition.
- Lack of use for any other purpose.
- Beneficial after use.

Walkover surveys which quickly reveal both favourable and unfavourable features are then carried out to help reduce the number of possible sites to a maximum of at least three. To further assist in the identification of the preferred site, it is necessary to develop conceptual designs for each remaining candidate site. Designs need to be taken to the point that approximate estimates can be made for comparative purposes on the:

- Site capacity.
- Volume of daily and final cover required.
- Resources needed to install an adequate leachate control system.
- Extent of surface water diversion works required.
- Extent of works required to provide all-weather access to the site.
- Cost of all the above, with the supplementary cost.
- Impact on the waste collection system.

A simple comparison may then be used to identify a preferred site, putting in mind the objective of protecting groundwater from contamination. Also the site must be suitable for long term stability.

SITE INVESTIGATION

Site investigations provide a firsthand knowledge of the geomorphology, lithology, stratigraphy and structures within the site. These site investigations are usually geomorphologic/geologic surveys and subsurface exploration which are carried out at the preferred sites. The results of the investigations should be interpreted by an experienced geotechnical engineer (or geophysicist) supported by a hydrogeologist. From the results of the site investigations, the estimates of costs, and capacity of the preferred site(s) may be firmed up and a clearly preferred site identified. The geomorphologic/geologic, geophysical and geotechnical investigates required are discussed below.

Geomorphologic and Geologic Investigations

These have proved over the years to be vital tools in site investigation. It enables the direct knowledge of the lithology, stratigraphy and structures (among others) within a site to be obtained. Study of aerial photographs (photogeology) is also useful as it augments field mapping by giving a foresight as to what obtains in the field as well as providing information on regional structures which may not be easily detected during field mapping (Ogunsanwo and Mands, 1998).

When conducting the field mapping, samples should be taken at all locations where the site preparation, construction, landfilling operation, closure and post closure care can affect environmental quality and all results should be presented with absolute levels of accuracy and precision. Criteria of utmost importance are:

- Surfacial geology of the project site and its surrounding areas.
- Soil characteristics of the project site (permeability, porosity, density, organic content).
- Geological hazards, slope stability, past occurrence of earthquakes and landslides.
- Present land use.
- Temperature (monthly averages).
- Surface hydrology of the project site and surroundings (natural drainage patterns, delineations of watershed, stream flow rates at gauging station and estimates of discharge at the project site).
- Hydrogeology of the project site and surroundings (ground watersheds, ground water table and estimates of ground water flow rates).
- Water resources and uses in the watershed (drinking water wells, reservoirs, springs fisheries, irrigation).

Rocks with undesirable properties and structures may be made suitable for use as repositories, once such properties are eliminated by means such as grouting where permissible (Nonveiller, 1989). This however can only be effective if the properties and structures have been well documented and can be accurately located as a result of a well executed field mapping.

Geophysical Investigations

Geophysical methods encompass a wide range of surface and down hole measurements techniques which provide a means of investigating subsurface geologic and hydrogeologic conditions (Benson, 1993). They are practically useful as they allow for a wide ground coverage in a short while. Geophysical methods can be successfully used both before waste disposal operations for evaluation of site characteristics and for monitoring of possible leachate flow (Saksa and Korkealaaskso, 1987; Benson, 1993).

There is a wide variety of geophysical sensing methods available and the more frequently used for environmental applications are summarized in Table 1 below. The best results are obtained when several geophysical methods are integrated to evaluate a given site. However, on account of ambiguity in geophysical interpretations, it is advisable to cross-check results obtained through a geophysical method by boring which is a geotechnical confirmation.

The information furnished by geophysical methods includes:

- Subsurface layers and their characteristics (e.g. topsoil, weathered layer, fresh bedrock, etc.).
- Depth to competent bedrock.
- Basement relief.
- Groundwater resources and nature of aquifer.
- Structural disposition of the subsurface (e.g. presence of faults, shear zones, etc.).
- Subsoil competence.
- Subsoil corrosivity.

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TABLE 1: GEOPHYSICAL METHODS FREQUENTLY USED IN ENVIRONMENTAL SITE ASSESSMENT (after Jewell et al., 1993).

Method	**Dependent physical property**	**Major applications**
Resistivity	Electrical conductivity	Soil type, stratigraphy, and depth to bedrock, degree of saturation, contaminant mapping, and cavity detection.
Frequency-domain electromagnetic (EM)techniques	Electrical conductivity	Soil type, stratigraphy, degree of saturation, contaminant mapping, cavity detection, location of buried objects.
Transient Electromagnetic(TEM)	Electrical conductivity	Faults, shear zones, contaminant mapping, soil type, stratigraphy, depth to bedrock.
Ground penetrating radar(GPR)	Dielectric permittivity	Location of water table, contaminant mapping, cavity detection, location of buried objects.
Seismic refraction	Elastic moduli	Bedrock lithology and profiling, overburden characteristics, degree of saturation, location of landfill boundaries.
Vertical seismic profiling(Surface to down hole)	Elastic moduli	Vertical and lateral changes in bedrock properties, anisotropy due to linear features such as faults and joints.
Magnetometry	Magnetic susceptibility	Fault location, bedrock lithology, cavity detection, location of buried objects.

Geotechnical Investigations

The satisfactory design and construction of any engineering structure can be accomplished when the characteristics of the soil or rock within which it is to be built is known (Blyth and de Freitas, 1984). For this knowledge to be obtained, the ground must be carefully studied by investigations conducted insitu or in the laboratory.

The most common and necessary procedure in making subsurface investigations is to drill holes using a drill rig on the chosen sites to extract samples of rock or soil or both for further study. Undisturbed samples are taken primarily for shear and consolidation tests which are generally essential for the design and analysis of foundations. Similar (undisturbed) samples may also be collected in all cases where the properties of the rocks and soils in place have to be studied. These generally furnish a satisfactory basis for judging whether or not a material is suitable for the given engineering project. Core boring may be applied in rocks or hard, cohesive soil samples. The depth of boring depends on the local geology and the load of the intended structure (Dimitri and William, 2001).

Generally, core samples are stored and transported in boxes which should be clearly labelled with the borehole number and site/ the levels from which the cores have been taken. For the purpose of landfill siting the following tests are of utmost importance:

- Tests for hydraulic property (permeability).
- Tests for strength (elastic moduli, consolidation characters, tensile strength, compressive strength, shear strength and swelling characters).

Field Measurement of Hydraulic Property

The permeability of the ground and its storage capacity are both calculated from a pumping test. In this test, a well is sunk into the ground and surrounded by observation holes of smaller diameter, which are spaced along lines radiating from the well. Two observation holes are generally held to be a minimum requirement (Figure 1). Pumping from the well lowers the water level in it and in the surrounding ground, so that a cone of depression results. By using values for the discharge from the well at given times, and the draw down measured in the holes at those times, and the known distances of the holes from the centre of the well, the permeability and storage of the ground can be calculated. Values for permeability only can be found from the rise in water levels which occurs when pumping stops: this is called the recovery method.

Permeability may also be measured in the field using either packers or piezometers, in existing boreholes. Figure 2 illustrates such an application. A packer is an inflatable tube, 1 or 2 meters long that can be lowered into a borehole and expanded radially to isolate the length of borehole

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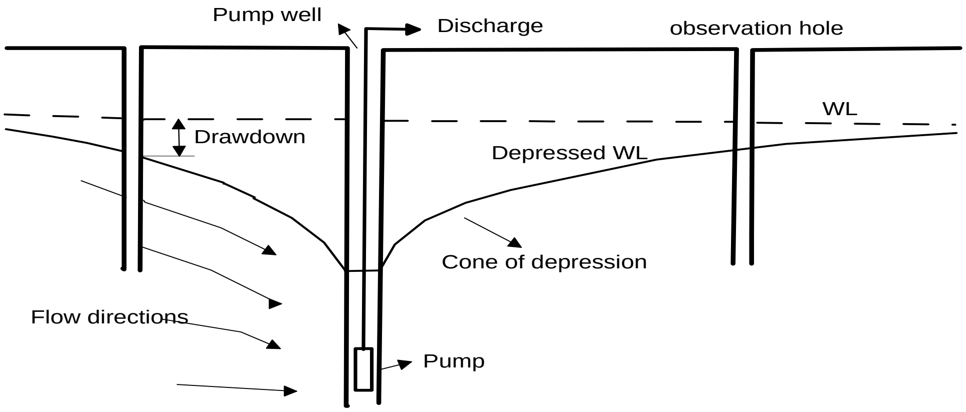

Fig. 1. Pumping test with observation holes

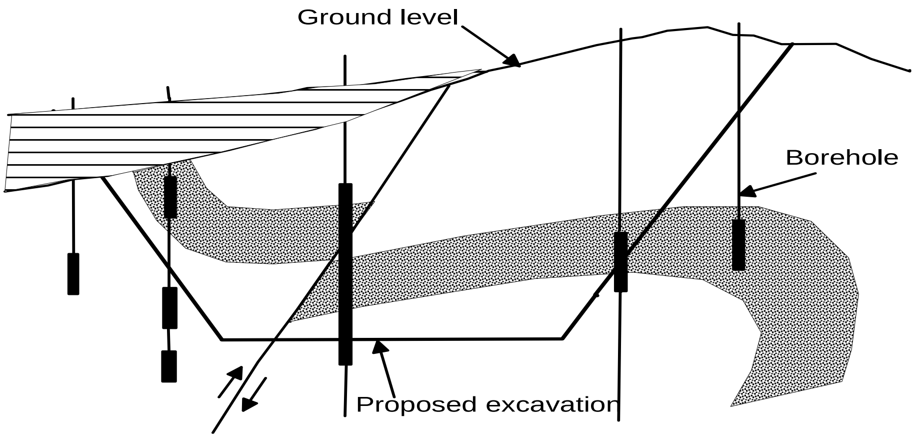

Fig. 2 Single hole permeability test

beneath it from that above. Two packers may be used to isolate a section of borehole from that beneath and that above. During a packer test water is injected into a section of borehole isolated by packers and from this discharge the permeability of the ground in the section can be calculated. While in carrying out the piezometer test water is injected into piezometers as illustrated in Fig. 3. to flow from their tip into the ground. From this flow, the permeability of the ground may be assessed.

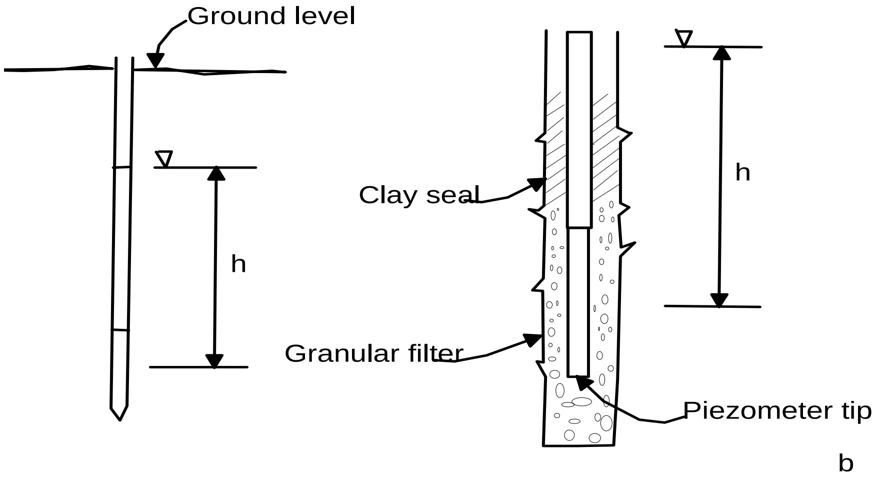

Fig.3 Stand pipe piezometers

a. Can be driven into the ground.

b. Is an installation in a borehole.

Laboratory Test for Hydraulic Property

Permeability is a measure of the velocity of fluid flow through a porous sample under the hydraulic head operating within the sample. The sample is housed in a permeameter as shown in Fig. 4. and permeability is calculated from the following relationship:

$$k = \frac{Q}{iA} \qquad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \qquad 1$$

where Q = the discharge, i = the hydraulic gradient = $\frac{\Delta h}{L}$, A = cross-sectional area of the sample measured at 90 degrees to the general direction of flow, and K = co-efficient of permeability.

The value of permeability obtained is a function of both the character of the fluid, that is, its specific weight and viscosity, and the nature of the pore spaces in the solid.

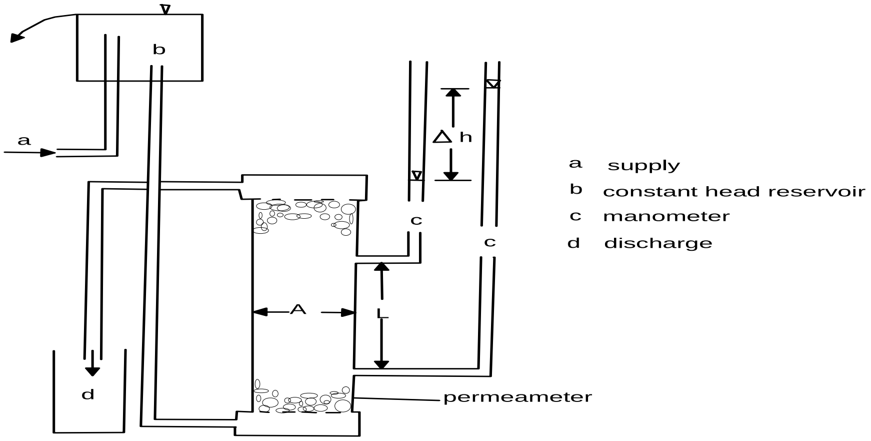

Fig.4 A constant head Permeameter

Field Measurement of Shear Strength

Shear stresses tend to move one part of a specimen with respect to the other or tend to make it flow (Dimitri and William, 2001). Figure 5 illustrates the test for use underground. The test arrangement can be modified for use at ground surface.

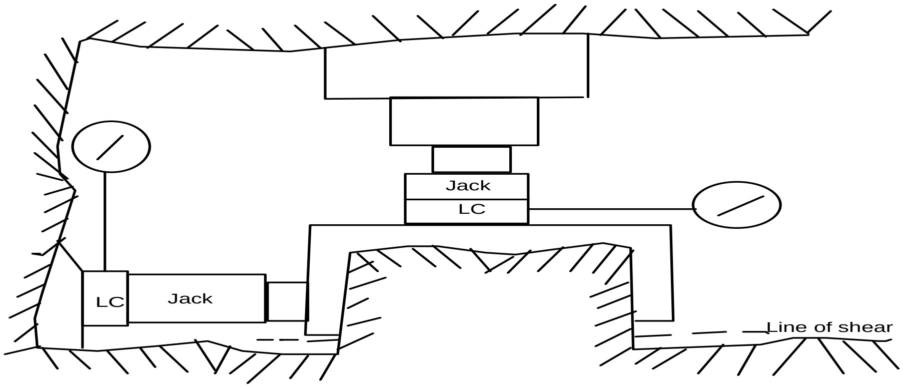

Fig. 5. Direct Shear test arrangement for use in adit
LC = Load cell.

The ground is loaded until shear failure occurs. This provides a value called the bearing capacity of the soil or rock, which is used to assess the maximum load that can be carried by a foundation bearing on the ground.

Other field tests include the penetration tests, where an indication of the relative shear strength of layered soil horizons may be obtained from the resistance they offer to penetration by a rod. A number of simple investigation methods are based on this principle. Three of these methods involve the use of probes, conical probes and cone penetrometer. Probes (rods) are used to locate boulders at depth in soft clay. The standard penetration tests measure the penetration of conical probe when it is hammered into the ground with a standard percussive force. Cone penetrometers are sophisticated and delicate probes which are gently and smoothly forced into the ground. This may be used in layered sequences containing peat, clay, silt, sand and fine gravel. Figure 6 illustrates a cone penetrometer.

Laboratory Tests for Strength

Elastic Moduli

Usually, if a material is loaded at stages; at each loading, the deformation is proportional to the load that caused it, the material is said to obey Hooke’s law of proportionality of stress to strain. The slope of the stress-strain curve is called the modulus of elasticity and is denoted by

$$E=\frac{\text{unit stress}}{\text{unit strain}} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \qquad 2$$

This can be obtained from statically loading cylinders of soil or rock and noting the resultant strains in directions normal and parallel to the direction of applied load. The modulus of elasticity and Poisson’s ratio can then be determined. The slope of the initial stress-strain curve in many specimens is less than that of the curves obtained in subsequent tests. This is generally attributed to the closing of voids and fissures which have opened during the collection of samples. It is normal to use the curves from second and subsequent loading cycles for analysis.

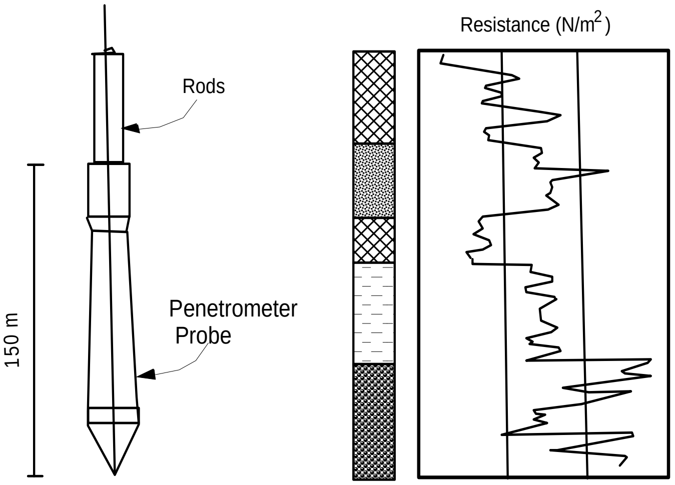

Fig.6 Cone Penetrometer and an example of a continuous log obtained for the soil profile, namely: made ground at the top, sand, peat, clay and gravel at the bottom

Consolidation Characters

The characters normally required are the coefficient of compressibility, which is the change in unit volume that occurs with a change in pressure (used to calculate the magnitude of settlements), and the coefficient of consolidation, which is proportional to the ratio of the coefficients of permeability and compressibility (used to calculate the rate of settlement). In the two laboratory methods generally used, a sample is compressed with a known load and the resulting changes in its volume with respect to time is measured. The simplest apparatus is an oedometer (Fig.7). In this equipment a sample is axially loaded in a cylindrical container that allows consolidation in one direction only i.e. vertically. Larger samples can be tested using a Rowe cell (Fig.8)

Consolidation in three dimensions can be obtained using triaxial apparatus (Fig.9), where a jacketed cylindrical sample can discharge pore water from its upper and lower ends. It is subjected to all-round pressures by pressurizing the fluid in the test cell, so that $\sigma x=\sigma y=\sigma z$ (Fig.9). Drainage facilities allow the pore water to escape from the sample, so that its volume decreases and consolidation occurs. Undisturbed samples are normally required.

Tensile Strength

Tensile stresses tend to produce cracks and fissures in materials. The tensile strength of both rocks and soils is negligible, but can still be measured in two ways. The simpler method loads test cylinders in tension until failure occurs, and a standard tensile testing rig is used.

The second method loads test discs in compression along a diameter, so inducing tensile failure on a diametral surface. Undisturbed samples are required for this test.

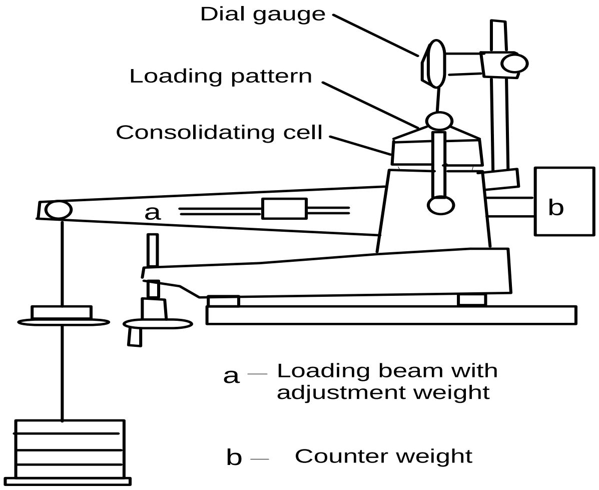

Fig.7 An Oedometer

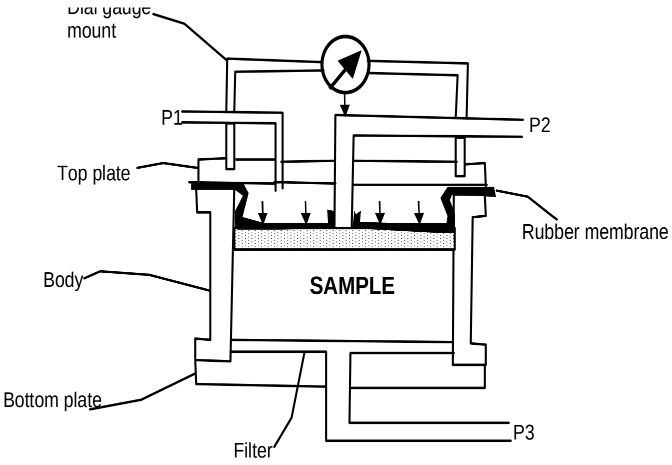

Fig.8: A Rowe cell

The sample is measured by hydraulic pressure P_1 and consolidated by drainage via P_3. Pore pressures can be measured at both ends of sample via P_2 and P_3. Dial gauge measures change in sample thickness.

Compressive Strength

Compressive stresses tend to decrease the volume of a material. The compressive strength of a material is the stress required to break a loaded sample that is unconfined at the sides (Dimitri and William, 2001). This is normally determined by statically loading a cylinder of rock to failure, the load being applied across the upper and lower faces of the sample. The results obtained are in part a function of the length – breadth ratio of the sample and of the rate of loading. Samples used in this test should be undisturbed.

Shear Strength

The compressive and shear stresses in rocks and other materials act simultaneously, and if a failure in a compressed rock occurs, this is generally a result of their common action. The shear strength of a soil or rock surfaces is best evaluated in the laboratory by using a shear box (Fig.10). This houses a normal loaded rectangular sample whose upper and lower halves can be subject to shear displacement about the centrally placed horizontal surface.

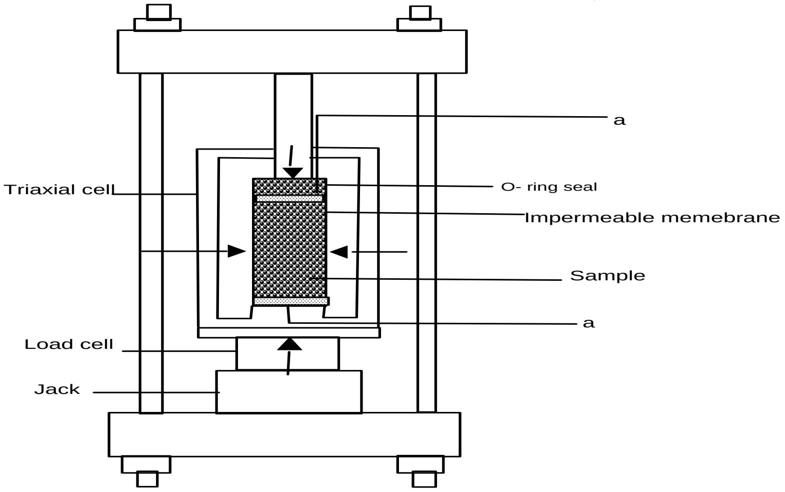

Fig.9 Triaxial cell
a = Lines for pore fluids.
b = Line for cell pressure and volume.

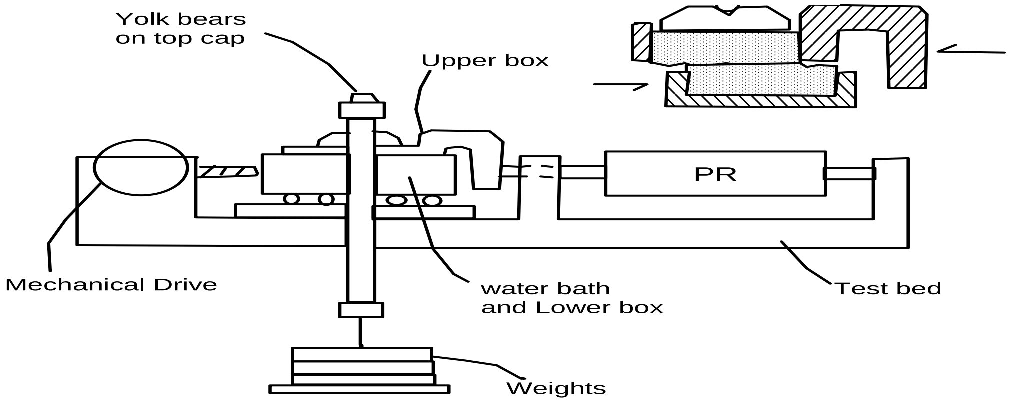

Fig. 10. Direct Shear box
PR = Proving Ring

SITE CONSTRUCTION

The design and construction of a landfill can follow one or two basic options for its control. It can either provide complete hydrogeological isolation of the site from its environment and permit only controlled discharge of leachate after treatment to an appropriate quality standard or permit leachates to attenuate by gradually seeping through the soils immediately underlying the waste before entry into the groundwater. The following data are considered relevant for planning, design and construction of a landfill facility:

- Anticipated amount and type of waste stored, the projected quantity and quality of material to be treated and the selection of the treated system.
- Life expectancy of the landfill during its operation life.
- The topography and soil characteristics near the site and the climatic conditions.
- Surface and ground water data in the proximity of the site and the monitoring of ground and surface water during the operating and post closure phases of the facility.
- Provision for venting gaseous products.
- Selection of durable, impermeable liners for the landfill.
- Provisions for closure and post closure of the landfill.
- Compliance with governing regulations.

Controlled dumping is usually the first step in ensuring sanity. Domestic and household garbage is collected and disposed by burial (Fig. 11). The advantage in the controlled dumping is that these operational improvements need little or no additional investments but begin the philosophy of introducing control and isolation into the waste disposal operation.

From controlled dumping to engineered landfill, the gradual adoption of engineering techniques to control and avoid surface water entering the waste extract and spread soils to cover wastes, remove leachates into lagoons, spread and compact waste into smaller layers, prepare new parts of the landfill with excavation equipment and improve the isolation of waste from the surrounding geology (Rushbrook and Pugh, 1995).

Figure 12 shows the basic components of an engineered landfill facility. The construction sequence is usually as follows:

- The site is excavated, generally bowl shaped with the bottom and sides reasonably smooth.
- A clay liner, normally about twelve inches thick is placed over the excavated surface.
- The outer bottom membrane is placed over the clay, glued or fused at joints and anchored at the top.
- A perforated pipe is placed at the bottom of the bowl, over the outer liner to collect and discharge any liquid that may escape the inner liner.

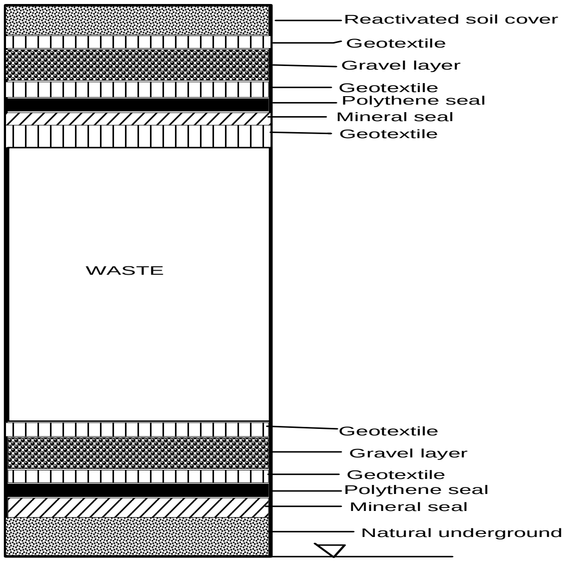

Fig .11 Cross-section of a domestic waste disposal landfill site

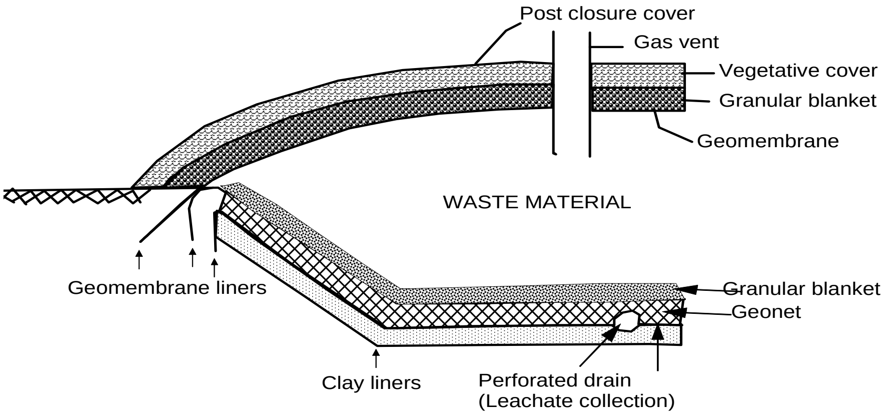

Fig..12 An idealized cross-section of an engineered landfill facility

- The next layer may be a granular (e.g. sand), highly permeable material or a geonet whose primary function is to facilitate drainage of any hazardous liquid that may escape the inner geomembrane liner to be collected by a second perforated pipe. A geonet also provides an added degree of reinforcement to the geomembrane liner against tearing.
- The inner top geomembrane is then placed and anchored to the top of the bowl.
- A granular blanket about 8-12 inches thick is placed over the inner liner to facilitate flow to the perforated pipe.
- The facility is capped following the functional life of the landfill to seal it from surface water. In order to direct surface runoff away, a small slope is constructed. Some additional soil cover, including some surface vegetation may be placed over the geomembrane cap to keep it from external damage and to provide an acceptable esthetic and possibly functional site.
- A vent is installed to permit the escape of gases that may be generated in the landfill.

The third stage is from engineered landfill to sanitary landfill which involves the continuing refinement and increasing complexity in the engineered landfill stage. In addition, sanitary landfills are more likely to have the preplanned installation of landfill gas control or utilization measures, extensive environmental monitoring, a highly organized and trained workforce, detailed record keeping by the site office staff, on-site leachates treatment to supplement a leachates collection system.

The techniques to develop away from open dumping towards sanitary landfills can be adapted to suit local conditions, materials and technologies. The attainment of highly complex landfill designs and construction is probably not immediately possible in some middle and lower-income countries. Small incremental improvements in landfill design and operation over several years are more likely to succeed than attempts to make a single, large leap in engineering expectations.

SITE MANAGEMENT

Leachates as earlier mentioned are formed by the passage of water through the materials, picking up contaminating substances in solution or suspension, its quantity and strength depends on the local climate, the nature of the wasteland the measures taken to control the entry of water into the wastes. Leachate quantities are greatest during the operational period of a landfill when waste is being deposited, but this declines slowly when landfilling ceases and after a thicker capping layer of low permeable soil has been put in place.

The problems associated with leachate may be minimized by limiting the amount of water getting into the waste. This can be achieved by a number of design and operational measures:

- Ensuring surface water does not enter the landfilled area by constructing interception ditches between the working and surrounding unused parts of the site.
- Covering wastes at the end of each day with soil or tarpaulins.
- Progressively completing and grading areas of the site with a capping layer, as they reach their final design heights.

Landfills should not only be designed and constructed to provide an acceptable level of protection to the environment; they need to incorporate systems which allow this protection to be demonstrated.

At the site preparation stage, certain facilities should be provided such as boreholes and sampling points to monitor the quality of the groundwater and the presence or absence of landfill gas. They allow the future impact of the landfill on the environment be measured at any time. A minimum of two groundwater monitoring facilities (drilled wells) should be installed down gradient to monitor the impact of leachate on the underlying groundwater (Fig.13). The location and design of these wells need to be decided carefully to sample adequately the expected contamination plume entering the groundwater. If the groundwater quality is shown to be deteriorating, then steps should be taken to protect the health of those using it as a water source. This could include stopping the use of some wells and providing alternative supplies of drinking water.

SITE RESTORATION

The most important part of a landfill closure and restoration plan is to construct a low permeability cover or cap over the waste when final elevations are reached. A cap constructed from a material such as clay is the most beneficial, but other materials can be used and their permeability modified, if nothing else is available. The following .procedures is typically proposed to close and restore a landfill:

- Cover all waste and any unstable areas of the landfill should be marked with barriers.
- Permit sufficient time for settling of any recently deposited wastes.
- Apply final covers.
- Grade final slopes.
- Install a permanent system of surface drainage channels (and cascade structures, where necessary on the landfill).
- Seed the final cover with the appropriate mixture of grasses and vegetation.

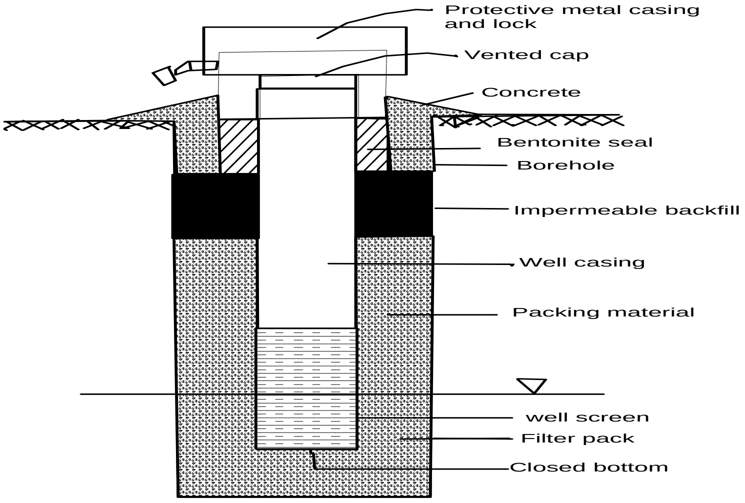

Fig..13 A typical ground water monitoring well

Near urban areas, there may be strong competing pressures to return landfills to an apparently normal land profile for potential after users like agriculture, recreation, habitation and so on, but no large structures that may exceed the load bearing capacity need to be built on open space of landfilled areas.

In all cases, the landfill cover should be deep enough to ensure that roots do not come in contact with the buried wastes because not only would such penetration be inhibitory to the growth of crop plants whether it be grass or trees it may also serve as an avenue for introducing harmful substances into the food chain and the environment.

The period of after-care should extend to the point that the site has stabilized physically, chemically and biologically to a degree that the wastes deposited in the site are unlikely to cause pollution or harm human health.

CONCLUSION

Nigeria and other developing countries with growing population and industrial activities need a proper waste management system, i.e. from open dumping, to controlled dumping, to engineered landfills and eventually to sanitary landfills. This will help attain high levels of protection for aquifers and surface waters, and low gaseous emissions. Experts in Engineering geology, Geophysics, and Hydrogeology should be fully involved in all the stages of selection, investigation, construction, monitoring and closure of sites for waste disposal.

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